Wesleyan Economics Working Papers

http://repec.wesleyan.edu/

N^{o}: 2005-009

Managing the Risks of Climate Thresholds: Uncertainties and Information Needs

Klaus Keller, Gary Yohe, and Michael Schlesinger

December 2005

WESLEYAN UNIVERSITY

Department of Economics
Public Affairs Center
238 Church Street
Middletown, CT 06459-007

Tel: (860) 685-2340
Fax: (860) 685-2301
http://www.wesleyan.edu/econ

Managing the Risks of Climate Thresholds:

Uncertainties and Information Needs

An Editorial Essay

Klaus Keller,[*,¶] Gary Yohe[‡] and Michael Schlesinger[§]

[*] *Department of Geosciences, Penn State, University Park, PA 16802*

[‡] *Department of Economics, Wesleyan University, Middletown, CT 06459*

[§] *Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, IL 6182*

Running Head: Managing the risks of climate thresholds

[¶] To whom correspondence should be addressed. E-mail: *kkeller@geosc.psu.edu*

Revised and Resubmitted to *Climatic Change*

1. Introduction

Human activities are driving atmospheric greenhouse-gas concentrations beyond levels experienced by previous civilizations. The uncertainty surrounding our understanding of the resulting climate change poses nontrivial challenges for the design and implementation of strategies to manage the associated risks. One challenge stems from the fact that the climate system can react abruptly and with only subtle warning signs before climate thresholds have been crossed (Stocker, 1999; Alley et al., 2003). Model predictions suggest that anthropogenic greenhouse-gas emissions increase the likelihood of crossing these thresholds (Cubasch and Meehl, 2001, Yohe et al, 2006). Coping with deep uncertainty in our understanding of the mechanisms, locations and impacts of climate thresholds presents another challenge. Deep uncertainty presents itself when the relevant range of systems models and the associated probability functions for their parameterizations are unknown and/or when decision-makers strongly disagree on their formulations (Lempert, 2002). Furthermore, the requirements for creating feasible observation and modeling systems that could deliver confident and timely prediction of impending threshold crossings are mostly unknown. These challenges put a new emphasis on the analysis, design, and implementation of Earth observation systems and strategies to manage the risks of potential climate threshold responses.

2. Needed information

A workshop at the Aspen Global Change Institute in July of 2005 assessed the information needs posed by potential anthropogenic crossings of climate thresholds. The participants concluded that reducing key uncertainties about climate thresholds is feasible. Doing so requires enhanced efforts in mission-oriented basic science (Stockes, 1997), research into the potential impacts of crossing such thresholds, and the design of strategies that could efficiently reduce the likelihood that those impacts would be experienced. The participants agreed that these efforts would be well informed by new approaches of analyzing risk management strategies, such as robust decision-making or optimal reliable strategies (Lempert et al, 2003, McInerney and Keller, 2006). These new approaches are required, for example, when the applicability of the more traditional expected-utility framework cannot be assured (Lempert et al., 2003; Tol, 2003). The expected utility analysis relies on a sound assessment of the economic impacts and the probabilities of the threshold responses. This information is, however, deeply uncertain at this time (Cubasch et al, 2001, Tol, 2003, Yohe et al., 2006). Robust decision-making (Lempert 2002, Lempert et al, 2003) seeks to identify strategies that perform well across a wide range of plausible impacts and a wide range of plausible probability density functions. Optimal reliable strategies limit the odds of undesirable outcomes in an efficient way (McInerney and Keller, 2006). Thinking in terms of risk management can help identify how and where reducing uncertainties could produce considerable social benefits (Yohe, 1996; Nordhaus and Popp, 1997; Keller et al., 2004). This includes exploring the high tail of the probability density function of climate sensitivity and estimating the locations of climate thresholds.

Table 1 summarizes lines of evidence that lead to these conclusions. It also indicates, through color-coding, the degree of confidence in this evidence (Schneider and Sarukhan, 2001). The subjective confidence in the threshold locations, ability for timely detection, and potential consequences are often "exploratory or speculative". Key lines of evidence about future climate thresholds are deeply uncertain. A potential collapse of the North Atlantic meridional overturning circulation (MOC) is a case in point. Current approaches of determining the location of the relevant forcing thresholds and the possible consequences of crossing them are still exploratory. The current uncertainties make timely prediction of a potential MOC collapse extremely difficult.

3. A Risk Management Approach

Potential threshold responses in natural and social systems play an important role in the interpretation of Article 2 of the United Nations Framework Convention on Climate Change [UNFCCC], wherein nations commit themselves to preventing "dangerous anthropogenic interference with the climate system" (UNFCCC, 1992). Persistent deep uncertainties about climate thresholds impede the design of climate policy under the UNFCCC. They cast doubt on the location of the critical boundaries and the attribution required to connect policy levers with policy targets. They also combine with uncertainty about climate sensitivity to question our ability to link specific concentration thresholds to reducing the likelihood of "dangerous interference".

Since the complexities of potential threshold responses undermine the applicability of expected-utility analyses, they underscore the importance of adopting more general risk management approaches. These approaches would support the design of long-term policy to avoid crossing critical thresholds of “dangerous” climate change. These would likely be specified under the UNFCCC as concentration or temperature targets and be implemented as emissions targets. These long-term targets should be adjusted over time as new information becomes available. The risk management approach also sheds light on how to design near-term policies that are consistent with “moving long-term targets”. Near-term policies could be framed as a hedge against the costs of policy adjustments. These could be implemented either by limiting the likelihood of crossing the thresholds (Keller et al, 2000; McInerney and Keller, 2006, Yohe et al., 2006) or by maintaining the feasibility of specific concentration or temperature limits (Yohe et al., 2004, 2005). Indeed, slowing the pace of climate change, even modestly, is a potentially efficient way of increasing the likelihood of confident and timely prediction of threshold crossings, even though this strategy might make the signal more difficult to detect. To be economically efficient, though, the adjustment process must be predictable and transparent, much like the predictable rules that define the anticipations of adjustments by markets in the conduct of monetary policy in countries such as the United States.

Textbooks (Stiglitz and Walsh, 2002) tell us that the Federal Reserve makes periodic short-term adjustments within the boundaries of long-term targets for growth in the money supply, even as research continues into defining the best policy targets in an uncertain world (Jensen, 2002; Walsh, 2003). The former chairman of the Federal Reserve Board Alan Greenspan (Greenspan, 2004) stated that these adjustments and the specifications of long-term targets are tempered by “crucial elements of risk management” (pg. 37). More specifically, the former Chairman wrote (pg. 37): “For example, policy A might be judged as best advancing the policymakers’ objectives, conditional on a particular model of the economy, but might also be seen as having relatively severe adverse consequences if the true structure of the economy turns out to be other that the one assumed. On the other hand, policy B might be somewhat less effective under the assumed baseline model but might be relatively benign in the event that the structure of the economy turns out to differ from the baseline." His words and the continuing debate over policy design can be cast into the context of how best to respond to the threat of climate thresholds. Hedging against even speculative descriptions of what might be "intolerable" impacts of crossing a threshold can make sense. The efficacy of such "act-as-you-learn" hedging can be improved by better information and further investigations of how to design adaptive mitigation strategies.

4. Implications for the Design of Research Portfolios

Climate thresholds pose deep intellectual challenges at the interface of pure and policy-relevant science. Reducing the risk of future surprises requires a balanced and diversified research portfolio that analyzes the range of possible thresholds. Possible elements of such a research portfolio that are likely to pay dividends include: (i) refining the probabilistic analysis of paleo-events to improve predictions of future climate change; (ii) characterizing the connections between monitoring and early prediction of threshold crossings; (iii) reducing the uncertainty of decision-critical parameters, such as climate sensitivity; (iv) estimating the impacts of threshold crossings; (v) analyzing strategies to reduce the risk of threshold crossings; and (vi) investigating ways of representing and communicating key uncertainties to decision-makers, stakeholders and the general public. It is important that the research portfolio covers many potential thresholds, ranked according to their importance. Currently, the threshold of a potential weakening or collapse of the MOC is drawing much of the attention, but it is not clear that it poses the most imminent or most dangerous threat.

While the current understanding of potential climate thresholds is uncertain, crucial information needs and research strategies for addressing them are becoming clear. Improving our understanding of the impacts associated with a growing list of possible thresholds and our understanding of how anthropogenic forcing affects their likelihoods is crucial to enhancing our ability to select long-term policy objectives and to craft short-term hedges for the effective management of climate risks.

5. Acknowledgements

We thank the participants of the recent Aspen Global Climate Change Institute workshop on abrupt climate change for insightful presentations and discussions (without implying the perfect agreement of all workshop participants). J. Baehr, D. Budescu, H. Garcia, P. Gent, J. C. Hargreaves, P. Higgins, D. Ludwig, M. Vellinga, G. Philander, R. Lempert, J. Scheffran, J. Severinghaus, A. Timmerman, R. Tol, M. Vellinga, and R. Wood provided inputs and detailed feedback on the manuscript. Any remaining errors are, of course, attributed to the authors. Financial support for the workshop from NOAA and from the National Science Foundation (SES 0345925 to K.K. and ATM 0084270 to M.S.) is gratefully acknowledged. G.Y. also recognizes with gratitude the contributions of B. Belle. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agencies.

References

Alley, R.B., J. Marotzke, W.D. Nordhaus, J.T. Overpeck, D.M. Peteet, R.A. Pielke, R.T. Pierrehumbert, P.B. Rhines, T.F. Stocker, L.D. Talley, and J.M. Wallace: 2003, 'Abrupt climate change', *Science*, *299* (5615), 2005-2010.

Cubasch, U., and G.A. Meehl, 2001, Projections of future climate change, in *Climate Change 2001 - The scientific basis. Contribution of working group I of the third assessment report of the Intergovernmental Panel on Climate Change*, pp. 526-582, Cambridge University Press

Fedorov, A.V., and S.G. Philander: 2000, 'Is El Niño Changing?' *Science*, *288* (5473), 1997-2002.

Fichefet, T., C. Poncin, H. Goosse, P. Huybrechts, I. Janssens, and H. Le Treut: 2003, 'Implications of changes in freshwater flux from the Greenland ice sheet for the climate of the 21st. century', *Geophysical Research Letters*, *30* (17), doi:10.1029/2003GL017826.

Greenspan, A.: 2004, 'Risk and uncertainty in monetary policy', *American Economic Review*, *94* (2), 33-40.

Gregory, J.M., K.W. Dixon, R.J. Stouffer, A.J. Weaver, E. Driesschaert, M. Eby, T. Fichefet, H. Hasumi, A. Hu, J.H. Jungclaus, I.V. Kamenkovich, A. Levermann, M. Montoya, S. Murakami, S. Nawrath, A. Oka, A.P. Sokolov, and R.B. Thorpe: 2005, 'A model intercomparison of changes in the Atlantic thermohaline circulation in response to increasing atmospheric CO_2 concentration', *Geophysical Research Letters*, *32* (12)

Gregory, J.M., P. Huybrechts, and S.C.B. Raper: 2004, 'Climatology - Threatened loss of the Greenland ice-sheet', *Nature*, *428* (6983), 616-616.

Hansen, J.E.: 2005, 'A slippery slope: How much global warming constitutes "dangerous anthropogenic interference"?' *Climatic Change*, *68* (3), 269-279.

Hargreaves, J.C., and J.D. Annan: 2006, 'Using ensemble prediction methods to examine regional climate variation under global warming scenarios', *Ocean Modelling*, *11*, 174-192.

Higgins, P.A.T., and M. Vellinga: 2004, 'Ecosystem responses to abrupt climate change: Teleconnections, scale and the hydrological cycle', *Climatic Change*, *64* (1-2), 127-142.

Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J.M. Pandolfi, B. Rosen, and J. Roughgarden: 2003, 'Climate change, human impacts, and the resilience of coral reefs', *Science*, *301* (5635), 929-933.

Jensen, H.: 2002, 'Targeting nominal income growth or inflation?' *American Economic Review*, *92* (4), 928-956.

Keller, K., K. Tan, F.M.M. Morel, and D.F. Bradford: 2000, 'Preserving the ocean circulation: Implications for climate policy', *Climatic Change*, *47* (1-2), 17-43.

Keller, K., B.M. Bolker, and D.F. Bradford: 2004, 'Uncertain climate thresholds and optimal economic growth', *Journal of Environmental Economics and Management*, *48* (1), 723-741.

Keller, K., M. G. Hall, S.-R. Kim, D.F. Bradford, and M. Oppenheimer: 2005, 'Avoiding dangerous anthropogenic interference with the climate system', Climatic Change, 73, 227-238, (2005).

Knowlton, N.: 2001, 'The future of coral reefs', *Proceedings of the National Academy of Sciences*, *98* (10), 5419-5425.

Latif, M., E. Roeckner, M. Botzet, M. Esch, H. Haak, S. Hagemann, J. Jungclaus, S. Legutke, S. Marsland, U. Mikolajewicz, and J. Mitchell: 2004, 'Reconstructing, monitoring, and predicting multidecadal-scale changes in the North Atlantic thermohaline circulation with sea surface temperature', *Journal of Climate*, *17* (7), 1605-1614.

Lempert, R.J.: 2002, 'A new decision sciences for complex systems', *Proceedings of the National Academy of Sciences of the United States of America*, *99*, 7309-7313.

Lempert, R.J., S.W. Popper, and S.C. Bankes, 2003, '*Shaping the next one hundred years: new methods for quantitative, long-term policy analysis'*, 187 pp., RAND corporation, Santa Monica, CA.

Link, P.M., and R.S.J. Tol: 2004, 'Possible Economic Impacts of a Slowdown of the Thermohaline Circulation: An Application of Fund', *Portuguese Economic Journal*, *3*, 99.

McInerney, D. and K. Keller: 2006, 'Economically optimal risk reduction strategies in the face of uncertain climate thresholds ' Climatic Change, in review.

Nordhaus, W.D., and D. Popp: 1997, 'What is the value of scientific knowledge? An application to global warming using the PRICE model', *Energy Journal*, *18* (1), 1-45.

Oppenheimer, M.: 1998, 'Global warming and the stability of the West Antarctic ice sheet', *Nature*, *393*, 322-325.

Oppenheimer, M., and R.B. Alley: 2004, 'The West Antarctic ice sheet and long term climate policy - An editorial comment', *Climatic Change*, *64* (1-2), 1-10.

Philander, S.G., and A.V. Fedorov: 2003, 'Role of tropics in changing the response to Milankovich forcing some three million years ago', *Paleoceanography*, *18* (2)

Rahmstorf, S., and K. Zickfeld: 2005, 'Thermohaline circulation changes: A question of risk assessment - An editorial review essay', *Climatic Change*, *68* (1-2), 241-247.

Schmittner, A., and T.F. Stocker: 1999, 'The stability of the thermohaline circulation in global warming experiments', *Journal of Climate*, *12*, 1117-1133.

Schneider, S.H., and J. Sarukhan, 2001, Overview of Impacts, Adaptation, and Vulnerability to Climate Change, in *Climate Change 2001 - Impacts, Adaptation, and Vulnerability. Contribution of Working Group II of the Third Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 75-103, Cambridge University Press

Stiglitz, J.E., and C.E. Walsh, 2002, in *Economics (Chapter 25)*, W. W. Norton

Stocker, T.F.: 1999, 'Abrupt climate changes: from the past to the future - a review', *International Journal of Earth Sciences*, *88*, 365-374.

Stockes, D.E., 1997, '*Pasteur's Quadrant'*, 196 pp., Brookings Institution Press, Washington, DC.

Timmermann, A.: 1999, 'Detecting the nonstationary response of ENSO to greenhouse warming', *Journal of the Atmospheric Sciences*, *56*, 2313-2325.

Timmermann, A., J. Oberhuber, A. Bacher, M. Esch, M. Latif, and E. Roeckner: 1999, 'Increased El Niño frequency in a climate model forced by future greenhouse warming', *Nature*, *398* (6729), 694-697.

Tol, R.S.J.: 2003, 'Is the uncertainty about climate change too large for expected cost-benefit analysis?' *Climatic Change*, *56* (3), 265-289.

UNFCCC, UN Framework Convention on Climate Change, Palais des Nations, Geneva, http://www.unfccc.de/index.html, 1992.

Vaughan, D.G., and J.R. Spouge: 2002, 'Risk estimation of collapse of the West Antarctic Ice Sheet', *Climatic Change*, *52* (1-2), 65-91.

Vellinga, M., and R.A. Wood: 2002, 'Global climatic impacts of a collapse of the Atlantic thermohaline circulation', *Climatic Change*, *54* (3), 251-267.

Vellinga, M., and R.A. Wood: 2004, 'Timely detection of anthropogenic change in the Atlantic meridional overturning circulation', *Geophysical Research Letters*, *31* (14), Art. No. L14203.

Walsh, C.E.: 2003, 'Speed limit policies: The output gap and optimal monetary policy', *American Economic Review*, *93* (1), 265-278.

Yohe, G.: 1996, 'Exercises in hedging against extreme consequences of global change and the expected value of information', *Global Environmental Change*, *6*, 87-101.

Yohe, G., N. Andronova, and M. Schlesinger: 2004, 'To hedge or not to hedge against an uncertain future climate', *Science*, *306*, 416-417.

Yohe, G., M. E. Schlesinger and N. G. Andronova: 2006, Reducing the risk of a collapse of the Atlantic thermohaline circulation, *Integrated Assessment Journal*, 6:1, 57-73.

Zickfeld, K., and T. Bruckner: 2003, 'Reducing the Risk of Abrupt Climate Change: Emissions Corridors Preserving the Atlantic Thermohaline Circulation', *Integrated Assessment*, *4*, 106-115.

Table Heading:

Table 1: Properties of potential threshold responses. The subjective confidence is color-coded in terms of the IPCC convention: "well established", "competing explanations", "established but incomplete", and "exploratory or speculative" (Schneider and Sarukhan, 2001). The temperature thresholds in the second column refer to the approximate changes in globally averaged surface temperatures relative to pre-industrial conditions. Note that some values (e.g., Oppenheimer and Alley, 2004) are based on a precautionary interpretation of the available evidence (Keller et al., 2005). The "timely detection" (third column) refers to an actionable warning sign for the threshold response (as opposed to the crossing of the approximate temperature or carbon dioxide concentration threshold) that would enable reversing the anthropogenic forcing to reduce the risk of the threshold response to low levels. The references given in the last column are a subset of key publications, more detailed analyses can be found in the references cited therein.

Climate Threshold	Threshold for Initiation	Ability for Timely Detection	Possible Consequences	Key References
Greenland Ice Sheet Melting	≈ 1.5 °C	Difficult, as threshold may be close	≈ 7 m sea-level rise, Possible MOC weakening, Damages depend on melting rate	(Gregory et al., 2004) (Hansen, 2005)
Coral Bleaching	≈1.5 °C	Difficult, as the threshold may be close	Ecosystem changes, Food production, Tourism	(Hughes et al., 2003) (Keller et al., 2005) (Knowlton, 2001)
El-Niño Southern Oscillation Changes	Deeply uncertain	Difficult	Precipitation and temperature changes, Ecosystem changes, Food production, Flooding	(Fedorov and Philander, 2000) (Philander and Fedorov, 2003) (Timmermann et al., 1999) (Timmermann, 1999)
MOC Weakening	Very low	Likely feasible	Precipitation and temperature changes, Fisheries, Terrestrial ecosystems	(Gregory et al., 2005) (Higgins and Vellinga, 2004) (Latif et al., 2004) (Link and Tol, 2004) (Vellinga and Wood, 2004)
MOC Collapse	≈ 2 to > 5 °C	Very difficult		(Fichefet et al., 2003) (Hargreaves and Annan, 2006) (Rahmstorf and Zickfeld, 2005) (Schmittner and Stocker, 1999) (Vellinga and Wood, 2002) (Zickfeld and Bruckner, 2003)
West Antarctic Ice Sheet Dis-integration	≈ 2.5 °C	Very difficult, fingerprints are uncertain and difficult to observe	≈ 5 m sea-level rise, Possibly severe *Damages depend on melting rate*	(Oppenheimer, 1998) (Oppenheimer and Alley, 2004) (Vaughan and Spouge, 2002)

Table 1